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DATA DRIVEN SPATIAL REASONING

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Advanced Automation Technology Center

SRI Project 8842

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Grant or Contract Title: Data Driven Spatial Reasoning
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Reporting Period: 1 October 1990—30 September 1991

1. Productivity measures, including numerical counts for the following aspects of the research project during this reporting period.

Refereed papers submitted but not yet published: 1 (accepted)

Refereed papers published: 0

Unrefereed reports and articles: 3

Books or parts thereof submitted but not yet published: 0

Books or parts thereof published: 0

Patents filed but not yet granted: 0

Patents granted (including software copyrights): 0

Invited presentations: 2

Contributed presentations: 1

Honors received (fellowships, technical society appointments, conference committee roles, editorships, etc.): 3

1. Co-chair, SPIE Conference on Intelligent Robots and Computer Vision X: Algorithms and Techniques (Boston, November 1991)
2. Program Committee, IEEE Workshop on CAD-based Vision (Maui, June 1991)
3. Program Committee, SPIE Conference on Applications of Artificial Intelligence X: Machine Vision and Robotics (Orlando, 21-23 April 1992)

Prizes or awards received (Nobel, Japan, Turing, etc.): 0

Promotions obtained: 0

Graduate students supported >= 25% of full time: 0

Post-doctoral researchers supported >= 25% of full time: 0

Minorities supported (including Blacks, Hispanics, American Indians and other native Americans such as Aleuts, Pacific Islanders, etc.; not including Asians or Asian-Americans): 0

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2. Detailed summary of technical progress.

Our research is aimed at the development of computational techniques for hypothesizing the shapes of hidden portions of unknown objects within a pile of such objects, using a dense range image of the pile.

The techniques that we have developed employ symmetry, stability, viewpoint independence, and object impenetrability to hypothesize the unknown shape and dimensions of each visible object. The process constructs alternative hypotheses, which differ in the way the visible portions of objects are extended into the occluded regions within the scene. To ensure that each interpretation is consistent with the observed range data, the known geometry of the range sensor is used in forming the hypotheses. The final result is one or more hypothesized object configurations, each of which is consistent with both the sensed range data and the physical constraints between objects in contact.

For each resulting hypothesis, a *free-body analysis is performed* to determine if the hypothesized configuration is stable. The hypothesis with the highest stability rating is chosen as the most likely correct interpretation.

Most prior work analyzing three-dimensional images of objects has concentrated on object recognition. Model-based techniques have concentrated on approaches to represent and recognize instances of known objects. Other work has concentrated on techniques for description of surface shape. Shape descriptions, from multiple range images covering all sides of an unknown object, have been used to develop geometric models or maps.

Our earlier work on interpretation using generic shape models, extension, and evaluation has been described elsewhere and has been used by others as a basis for applying Dempster-Shafer theory to shape recognition. In the 1990-1991 reporting period, we have extended our previous work to cover a complete exploration of possible configuration hypotheses and their evaluation using free-body analysis in the presence of friction. This integration of vision and mechanics has not been significantly explored by other researchers.

We begin with three basic pieces of knowledge: a range image of a scene, the geometry of the sensor used to acquire the image, and the expectation that the scene consists of objects whose geometries can be represented by a set of generic shapes (e.g., boxes and cylinders).

The range image contains the three-dimensional location of visible points on the surfaces of unknown objects in a pile. These surfaces occlude the volumes of the objects within the scene; these are the hidden volumes we wish to explore.

We expect our scene to consist of objects whose shapes are familiar but whose dimensions are unknown. In our work, we restrict these shapes to prismatic solids and cylinders whose dimensions are unknown.

Given the information about the image, the sensor, and the expected shapes, we look for surface patches consistent with our expected shapes. From these primitive shapes, we form a hypotheses about the configuration of the objects in the scene. Due to occlusion, we only have incomplete information about the object extents, and therefore multiple hypotheses are possible. We use a free-body analysis technique for evaluation of each hypothesis.

Each final hypothesis for the configuration of the pile accounts for all the visible data. Thus, from an image-processing standpoint, there is no way to discriminate among these alternative configurations. We therefore turn to a nonvisual approach, using the physical consequences (stability) of each proposed configuration to rule out impossible arrangements and to rank the remaining plausible hypotheses.

We analyze the balance of forces and torques within each hypothesized configuration of the pile. Treating each object within the hypothesized configuration of the pile as a free body, this process evaluates all the *gravitational* and contact forces acting on it. Following a technique described by Fahlman, we attempt to find a static solution, i.e., the assignment of plausible forces to each contact point such that the vector sum of all forces and the vector sum of all torques on the object each totals zero.

This free-body analysis procedure partitions the objects of an hypothesis into two classes: balanced and unbalanced. For the hypothesis corresponding to the true configuration of a pile, we expect all objects to be in the balanced class.

We establish a stability rating for each hypothesis as the number of balanced objects divided by the total number of objects. Thus, a completely balanced hypothesis has a rating of 1.0, while all others are assigned lower values.

The techniques described above for the generation and evaluation of alternate hypotheses for the configuration of a pile of objects have proven useful. They predict the size and shape of the hidden portions of generically shaped objects in a scene. They also estimate the force relationships among the objects.

These techniques, like the hidden regions they hypothesize, seem to be relatively unexplored by image understanding research. One immediate possibility for further research is the inclusion of a larger set of generic shapes. This would not only make the process more robust but would also help define its limits.

In the longer term, the free-body analysis outlined above could be pushed forward in the image understanding process. It could be used to suggest the appropriateness of one extension over another in order to reduce the explosive number of alternative hypotheses. Beyond that, it might be used to suggest the existence of an entirely unseen object underneath the pile.

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3. Publications, presentations, and reports.

Mulgaonkar, P.G., "Scene Description: An Iterative Approach," *Proc. SPIE Symposium on Intelligent Robots and Computer Vision IX: Algorithms and Techniques*, Boston, Massachusetts, 4-9 November 1990.

Mulgaonkar, P.G., Cowan, C.K., and DeCurtins, J., "Understanding Object Configurations Using Range Images," Accepted for publication in the *IEEE Trans. Pattern Analysis and Machine Intelligence, Special Issue on 3D Computer Vision*, to be published in late 1991.

DeCurtins, J. and Mulgaonkar, P.G., "Scene Description: Interactive Computation of Stability with Friction," Invited paper, SPIE Symposium on Intelligent Robots and Computer Vision IX: Algorithms and Techniques, Boston, Massachusetts, November 1991.

Mulgaonkar, P.G., Cowan, C.K., and DeCurtins, J., "Understanding Object Configurations Using Range Images," Submitted to the IEEE Conference on Computer Vision and Pattern Recognition, 1992.

Mulgaonkar, P.G., Cowan, C., and DeCurtins, J., "A System to Understand Object Configurations Using Range Images," SRI International Technical Note, ITAD-8842-TN-91-6, June 1991.

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4. Transitions and DoD interactions.

None have taken place.

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5. Software and hardware prototypes.

SRI has developed a Sun-based software system, written in C, for interpreting dense range images. The system is portable and can be modified to process range images from different sources. The results are displayed graphically on a color monitor for evaluation.